NETL Carbon Storage Research

Enhancing the Success of Carbon Storage Technologies

High Level Goals

- Technology to Demonstrate 99% Permanence
- Predict Storage Capacity to ± 30%

NETL-RUA Approach

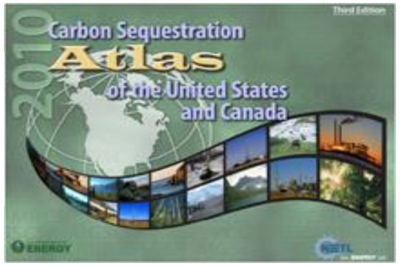
- Develop Methodology for Storage Potential
- Laboratory and Numerical Studies of Reservoir and Seal Performance
- Develop Technology to Verify Storage Permanence
- Develop Geospatial Data Resources

Participants

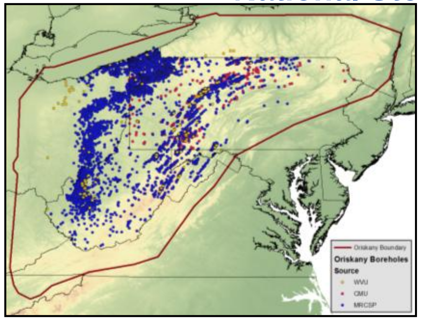
- NETL-ORD
- RUA Partners: CMU, Pitt, PSU, VaTech, WVU
- Other Partners: OSU, UKansas, CCUS Regional Partnerships

National Data Resources

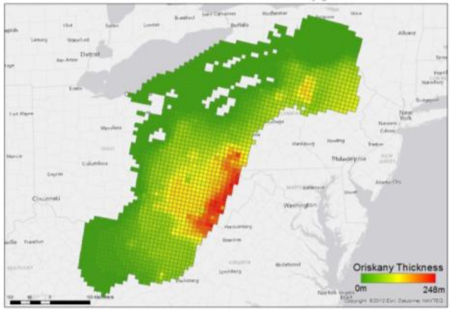
EDX
Energy Data eXchange



National Storage Estimates

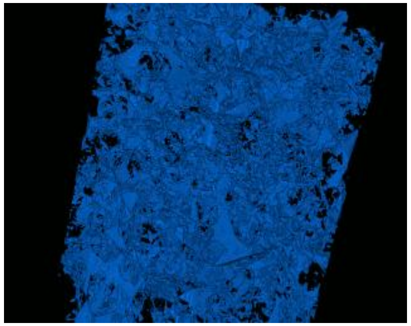


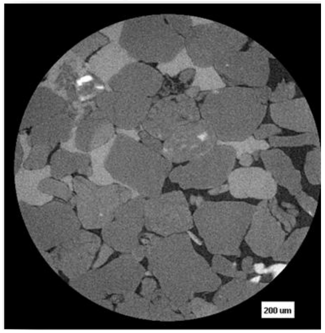
Oriskany Formation wells



Oriskany Formation thickness

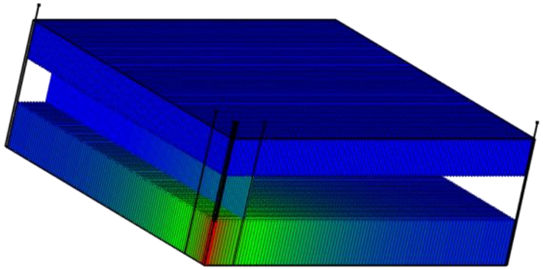
Laboratory Studies of Flow Properties



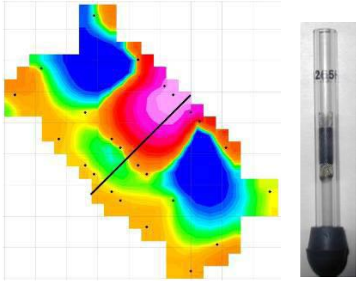


Imaging of Reservoir Rock Pore Structure

Monitoring Technologies



Pressure Plume Propagation



Surface Tracer Detection

Contacts

- **TC – Brian Strazisar**
- **FAL – George Guthrie**
- **DD's – Karl Schroeder, Jamie Brown, Mary Ann Alvin**
- **TTC's:**

Task #	TTC	Title
2.1	Yee Soong	Impact of Co2-Brine Rock Chemistry on Storage Formations and Seals
2.2	Angela Goodman	Impact of Microbial Processes on Storage Formations and Seals
2.3	Daniel Soeder	Impact of CO2 on Shale Formations as Seals
2.4	Dustin McIntyre	Characterization of Reservoir and Seal Material Performance
2.5	Grant Bromhal	Understanding of Multiphase Flow for Improved Injectivity and Trapping
3.1	Angela Goodman	Improved Mineral Reaction Kinetics
4.1	Daniel Soeder	Methodology for assessment of unconventional systems
4.2	Robert Dilmore	CCUS CO2 Storage Resource Assessment
5.1	Karl Schroeder	Natural Geochemical Signals to Monitor Leakage to Groundwater
5.3	Arthur Wells	Development of Technology to Monitor CO2 and Pressure Plume
6.1	Daniel Soeder	Atlas development and NATCARB
6.2	Kelly Rose	Geodatabase Development - EDX

Task 2.1 – Impact of CO_2-brine rock chemistry on storage formations and seals

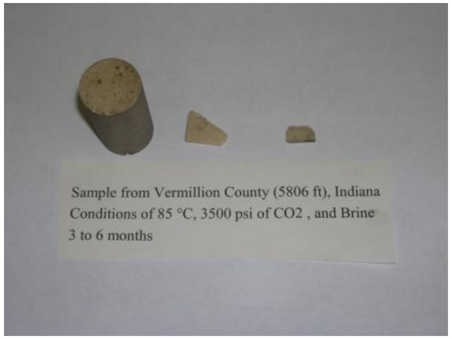
Soong, Hedges, Irdi, Haljasmaa, Warzinski, Howard, Rosenbaum, Romanov, McIntyre, Crandall, Bowen (UU) and Rupp (IGS)

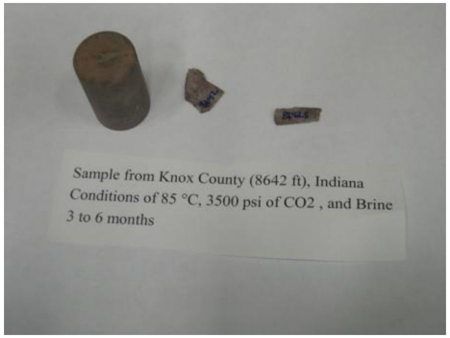
Background : CO_2 injection can introduce significant perturbations of the rock formations (reservoirs and seals) that may affect the storage capacity, injectivity and permanence of CO_2 storage.

Goal : To understand the impacts of CO_2-brine-rock interactions on chemistry process, porosity, permeability properties on storage formations and seals.

Status: Completed two six months of CO_2/brine/Mount Simon sandstone exposure experiments under sequestration conditions (85 C and 3500 psi of CO_2). The results indicated the changes of permeability of the formation rock as a result of mineral dissolution and mineral precipitation.

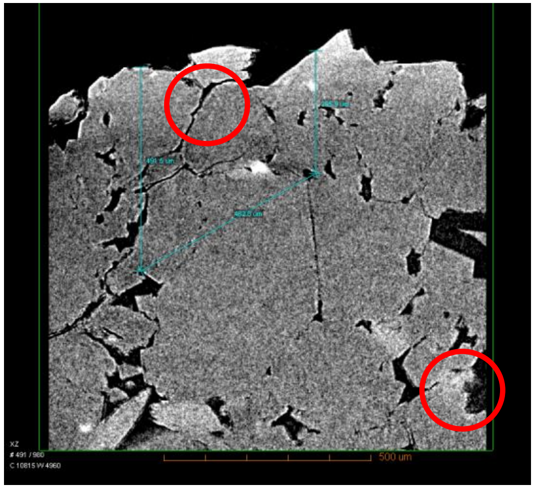
In progress: Two six months of CO_2/brine/Lower Tuscaloosa sandstone/sale exposure experiments under sequestration conditions (85 C and 3500 psi of CO_2) have been initiated.



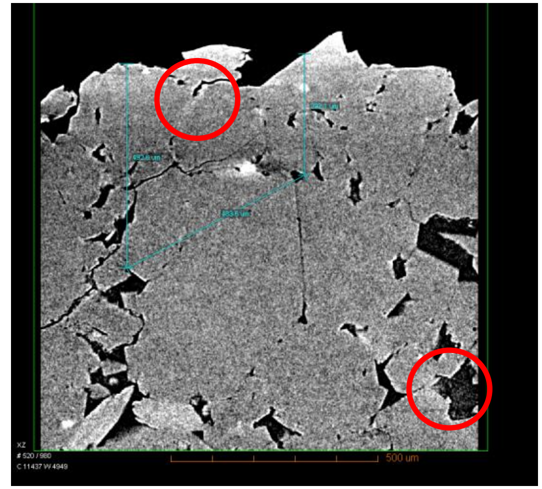


Task 2.1 – Impact of CO_2-brine rock chemistry on storage formations and seals

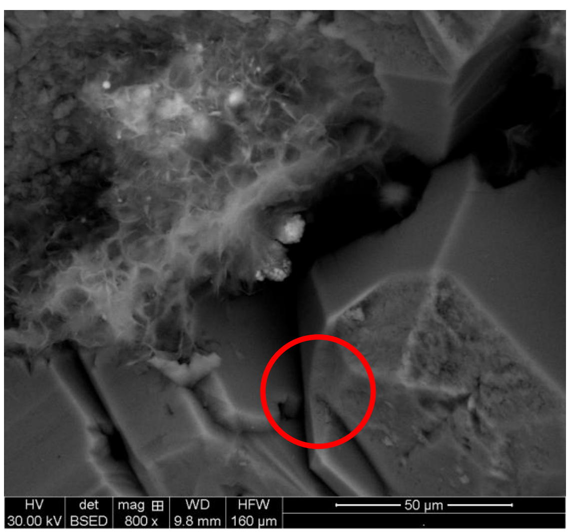
Sample from Vermillion CO (5806’), IN before and after 6 month in CO_2/brine (85 °C and 3500 psi), permeability reduced by 50%



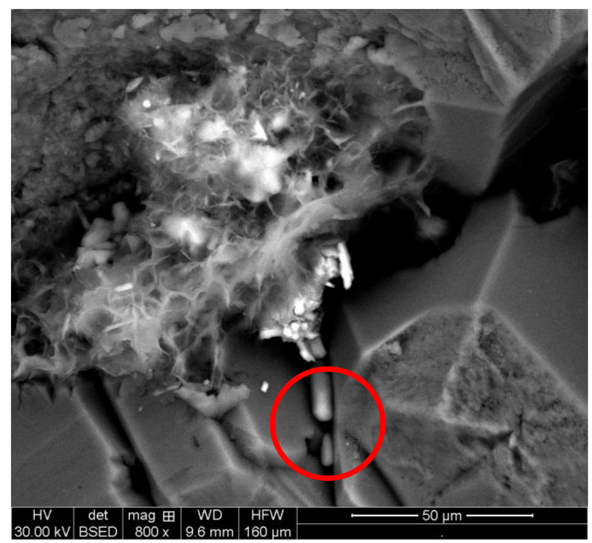
CT



After 6 month, mineral dissolution and mineral precipitation occurred



SEM

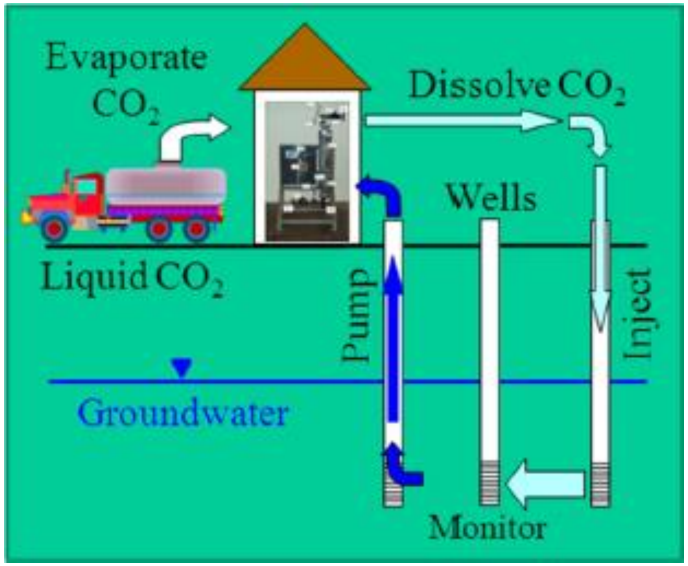


Fresh

Exposed to CO2/Brine 6 months

2.2 Impact of Microbial Processes on Storage Formations and Seals

- *Goal:* Characterize microbes present in CO_2 storage reservoirs and examine the impact that CO_2 injection could have on altering the microbial community and ultimately how rock permeability and porosity could be impacted.
- *Method:* Assess native microbial community using standard DNA analysis methods and use batch exposure experiments to determine the potential for change due to CO_2 injection.
- *Sites:*
  - Columbia River basalts at Wallula Pilot Study, OR
  - Arbuckle Saline Aquifer, Wellington, KS.
  - Mirando Oil Reservoir in Zabata, Texas:
  - EPRI Plant Daniel in Escatawpa, MS:
  - East Seminol Oil Reservoir, Gaines County, TX
- *Results:*
  - No Archaea detected in raw water
  - Microbial cell viability decreased at CO_2 exposures of 0.1 MPa and above



Plant Daniel in situ Experiment

- Effect of dissolved CO2 on shallow groundwater system: a *Controlled Release Field Experiment*, Details found in Trautz et. al, **Environmental Science and Technology**, January, 2013

Rick Colwell, OSU; Corinne Disenhoff, URS; Heather Lavalleur, OSU; Circe Verba, NETL Kelvin Gregory, CMU; Djuna Gulliver, CMU; Angela Hartstock, NETL, Barbara Kutchko, NETL; Gregory Lowry, CMU

Task 2.3 Shales as Seals

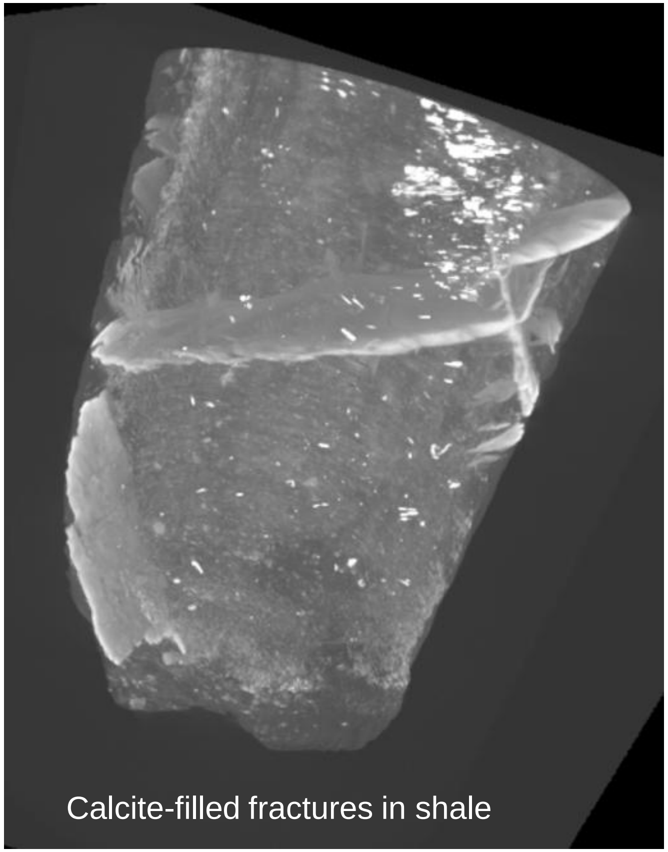
- **Programmatic Goals: Understand the performance of shales as seals for CO2 storage reservoirs.**

- **End of Project Goal: Define relative permeability and capillary entry pressure on a variety of shale types, and determine how pore structures and flowpaths may be affected both by changes in net stress and exposure to CO2.**

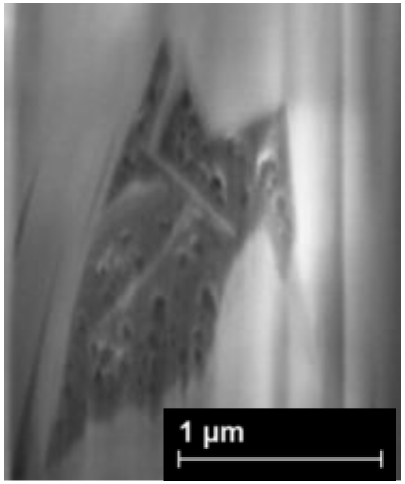
- **Current Objectives: Assess performance and application of shale pore visualization methods; investigate capillary barriers and gas-liquid interfaces in shales.**

Task 2.3 Shales as Seals

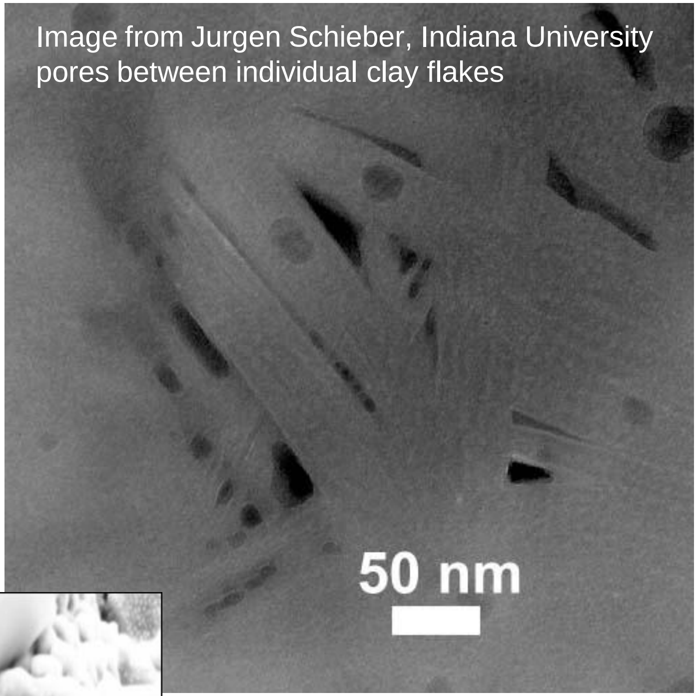
Shale pore visualization assessments


Calcite-filled fractures in shale

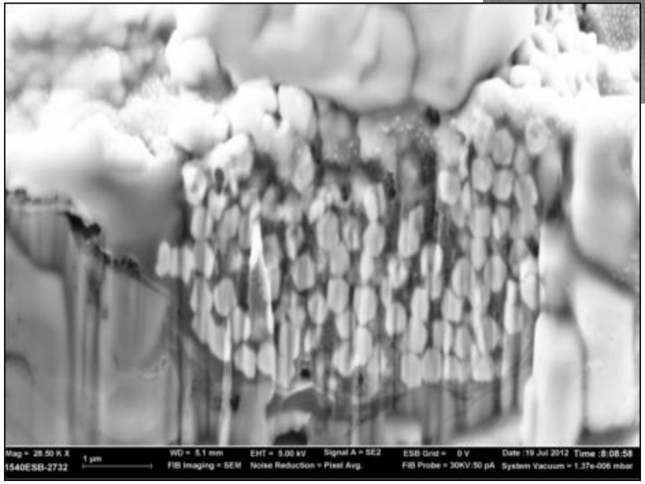
Micro C-T Scanner at NETL



Pores in organic matter



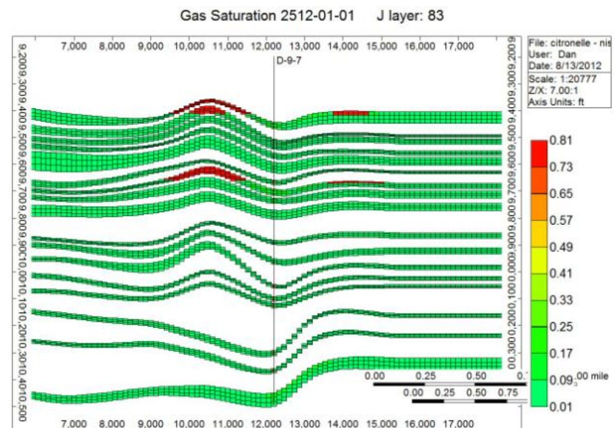
Transmission Electron Microscope (TEM)

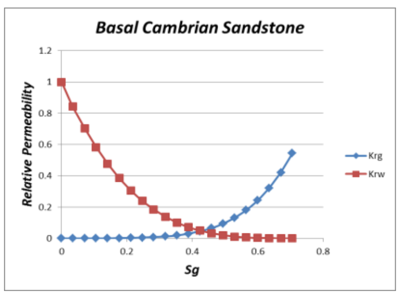

Pores in framboidal pyrite

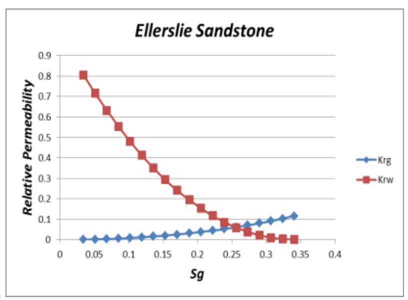
< Ion-beam milled surface under Scanning Electron Microscope (SEM) at LBNL

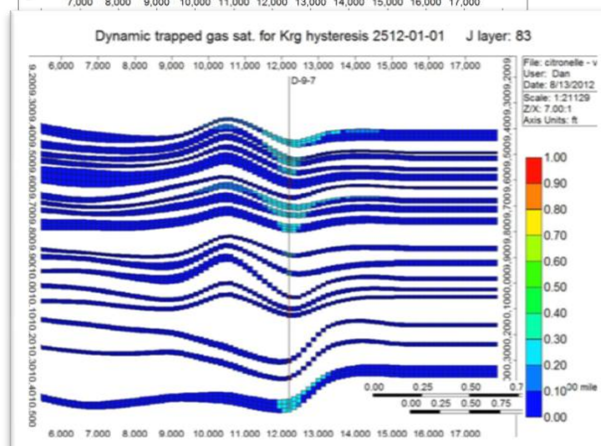
2.5 Understanding of Multiphase Flow for Improved Injectivity and Trapping

- Reservoir Scale Impacts of Relative Permeabilities and Residual Saturations on Injectivity and Capillary Trapping
  - Using reservoir simulation studies
  - Multiple formations
  - Several different relative permeabilities
  - Effects of hysteresis
  - Long-term trapping



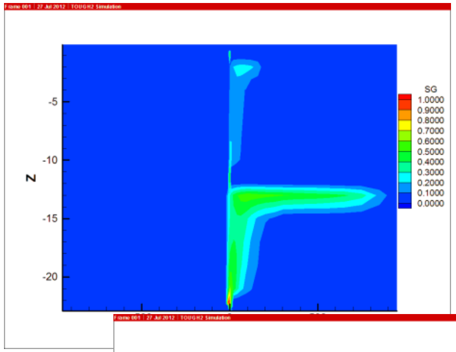


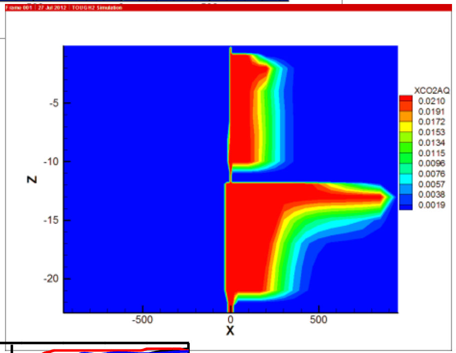




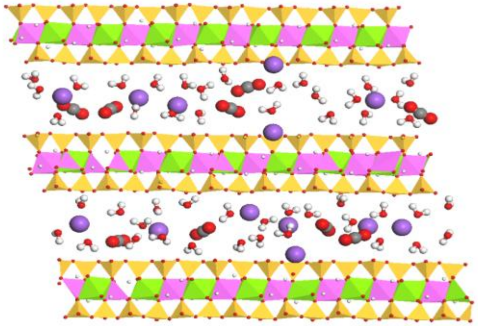
2.5 Understanding of Multiphase Flow for Improved Injectivity and Trapping

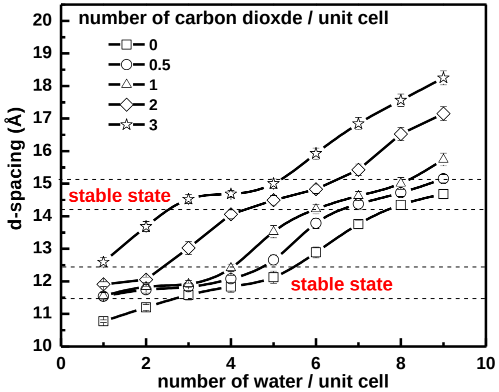
- Estimation of CO_2 Losses along Leakage Pathways between the Reservoir and the Near Surface
  - Varied leakage rate, Kv/Kh, cross flow rate
  - Strong interplay between the different variables
  - No clear reln between leakage and seepage rates yet

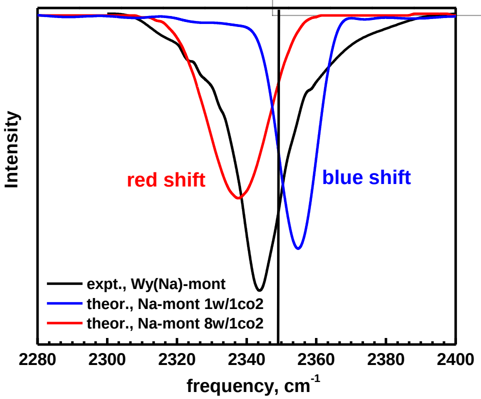




- CO_2 Trapping Mechanisms in Clay Materials
  - Predicting clay swelling due to CO_2
  - Amount of swelling depends on water present
  - Experimental and theoretical





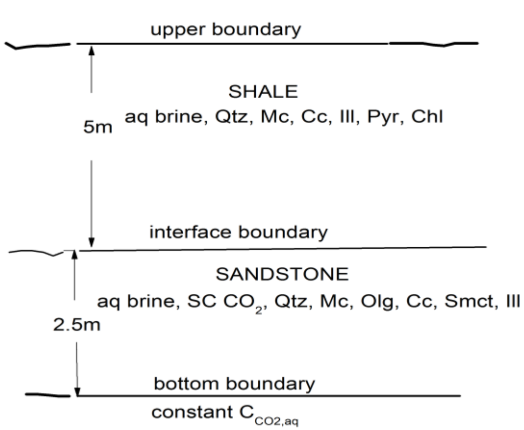


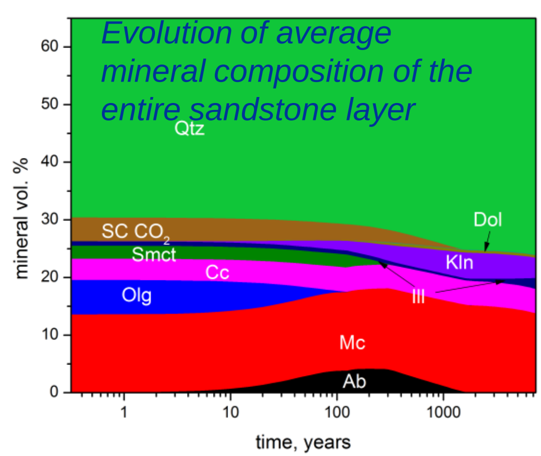
3.1 Improved Mineral Reaction Kinetics

- *Goal:* Determine the mineral precipitation and dissolution processes that are important to storage permanence at brine/aquifer/caprock interfaces.
- *Importance:*
  - Geochemical calculations are needed for prediction
  - Calculations rely on uncertain thermodynamic & kinetic databases
  - lab and field rates vary by factors of 10^5 (White & Brantley, 2005)
- *Conclusion:* The precipitation and dissolution processes for minerals Kln, and carbonates Cc, Dol, Ank are important to the permanence of CO_2 storage at the brine/aquifer/caprock interfaces.

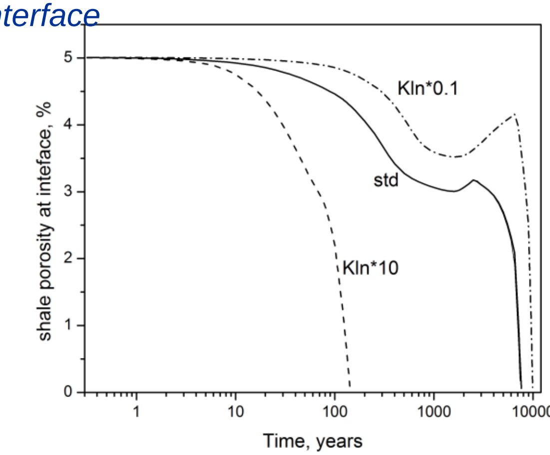
Baseline Shale Mineralogy

Mineral	Composition	mass %
quartz	SiO_2	38
calcite	$CaCO_3$	5
smectite	$KAl\,Si_3O_8$	2
Illite (+mica)	$KAl_3Si_3O_{10}(OH)_2$	35
pyrite	FeS_2	5
chlorite	$Mg_{2.7}Fe_{1.8}Fe(III)_{0.12}Al_{1.38}Al_{1.5}Si_3O_{10}(OH)_8$	15
porosity	--	5



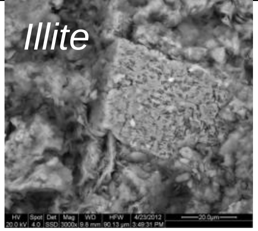


Critical evolution of shale porosity at the interface



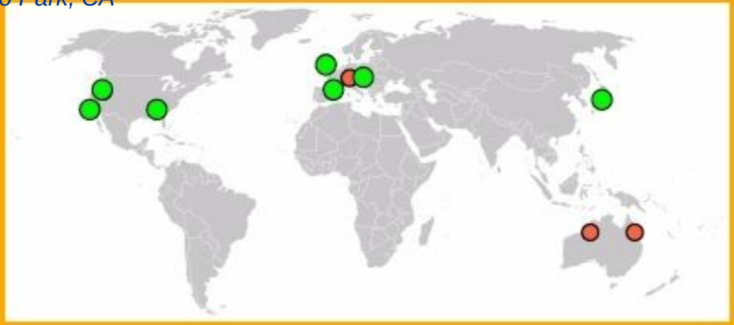
Victor Balashov, PSU; Sue Brantley, PSU; George Guthrie, NETL; Ale Hakala, NETL; Christina Lopano, NETL

International Inter-lab Round Robin Collaboration



Organized and led by the Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany and the United States Geological Survey (USGS), Menlo Park, CA

partners for interlab comparison



Motivation:

- to provide an estimate of potential variance in kinetic (or thermodynamic) data derived from gas-fluid-mineral interaction experiments using different experimental approaches in a variety of labs.
- to validate kinetic data for dissolution of three minerals
- to strengthen the collaboration among experimental labs around the world and to streamline experimental programs for gas-fluid-mineral reaction studies.

Participants	Country
Bundesanstalt für Geowissenschaften & Rohstoffe	Germany
United States Geological Survey	US
RWTH Aachen	Germany
GFZ Potsdam	Germany
MLU Halle	Germany
IFM-GeoMAR	Germany
British Geological Survey & University of Leeds	GB
Université Henri Poincaré, Nancy	France
Lawrence Livermore National Lab	US
US Department of Energy *	US
Research Institute of Innovative Technology (RITE)	Japan
University of Queensland	Australia
Geoscience Australia / CO2CRC	Australia

Bob Dilmore, NETL; Angela Goodman, NETL; Sheila Hedges, NETL; Athanasios Karamalidis, CMU

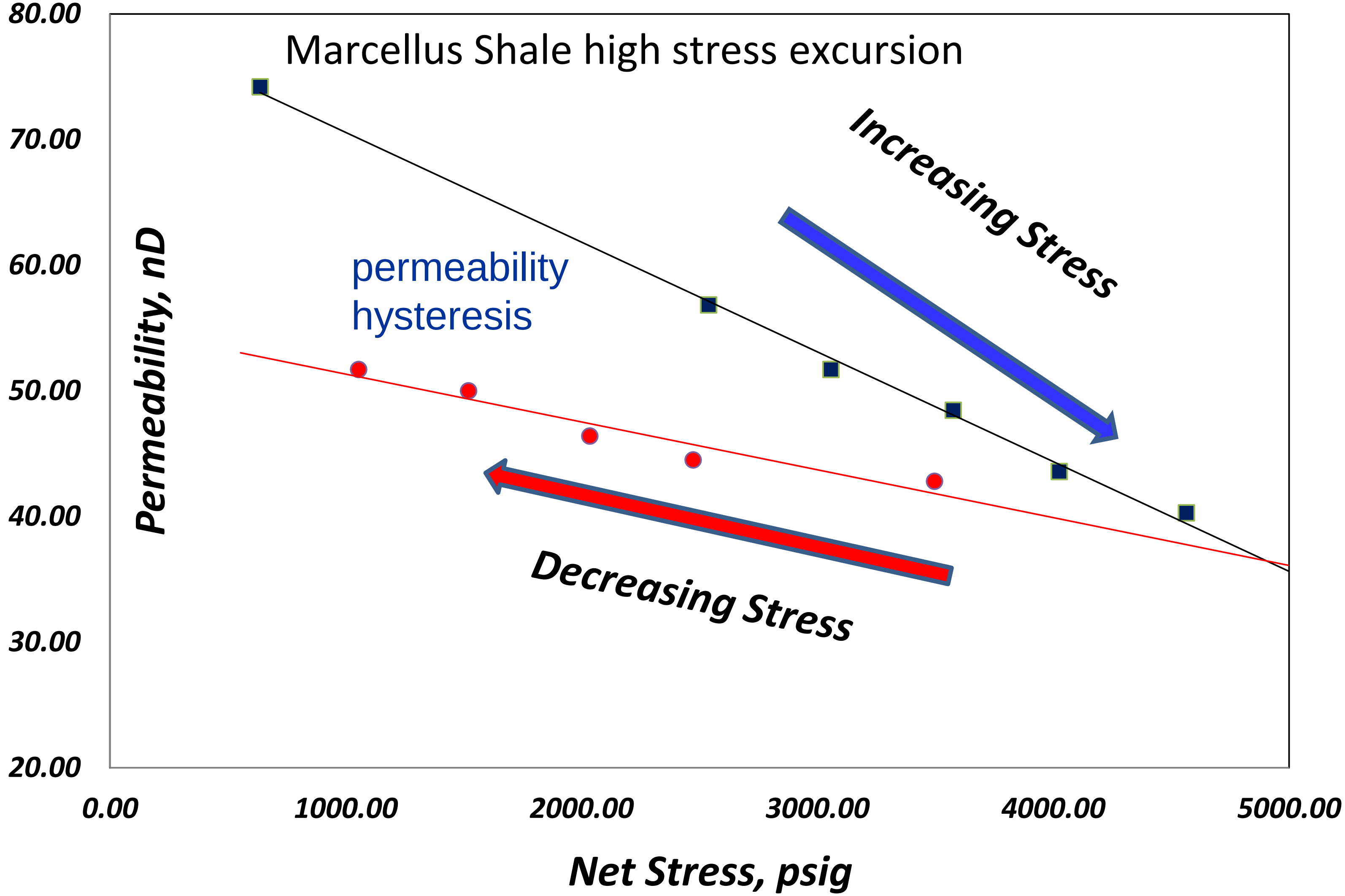
Task 4.1 Methodology for Assessment of Unconventional Systems

- **Programmatic Goals: Adapt methodology for coal to gas shale and basalt.**

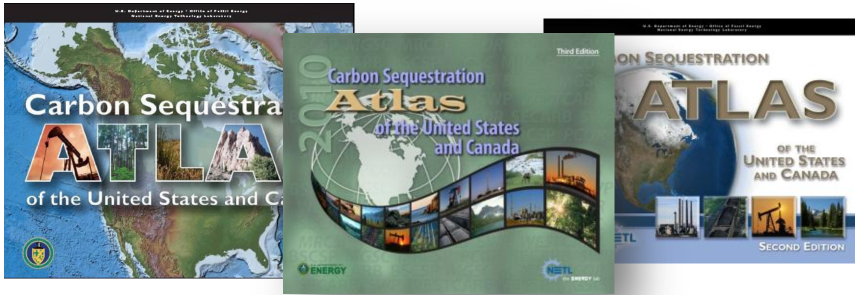
- **End of Project Goal: Methodology to assess basin-scale storage resources in shales using publically-available data under defined conditions.**

- **Current Objective: Define net stress effects during drawdown for gas shales and link to geology. (Assumption: gas shales will not be available for storage until depleted.)**

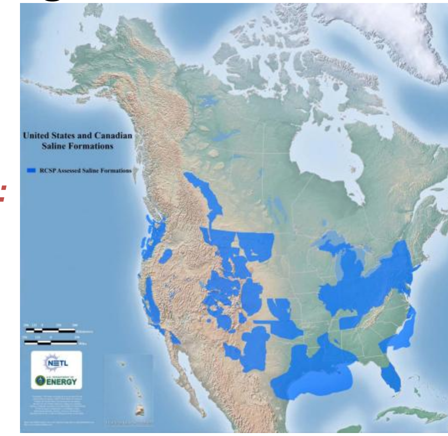
Task 4.1 Methodology for Assessment of Unconventional Systems



Evaluation of DOE's Methodology for Estimating Storage Potential by Comparison with Other Common Methodologies



Atlas III Estimates for Storage Potential in Saline Formations:
1,653 - 20,213 GT CO_2



Driver:

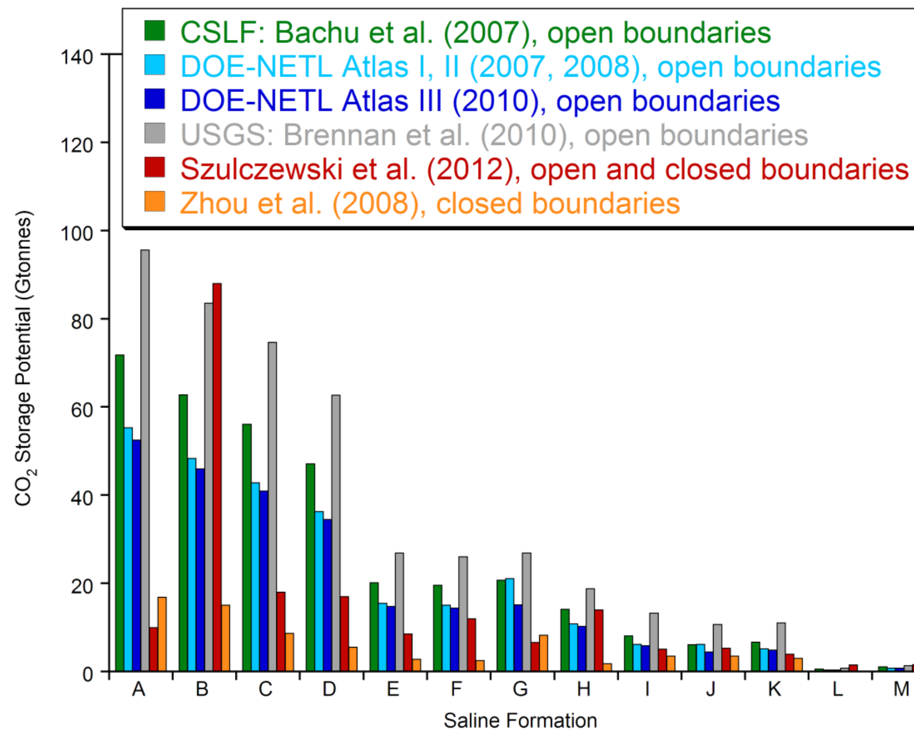
- Build confidence in storage-potential estimates used for decisions related to CCUS by assessing uncertainties due to different methodologies

Approach:

- Compared six widely used CO_2 storage methodologies (including DOE's methodology)
- Applied to 13 synthetic saline formations drawn from data on major US storage formations

Results:

- Methodologies for open-boundary conditions gave comparable estimates (statistically equal)
- Closed-boundary methodologies gave lower estimates (to be expected)
- Provides confidence in Atlas IV estimates



Team Members: Angela Goodman, Grant Bromhal, Brian Strazisar, Traci Rodosta, and George Guthrie

4.2 CO_2 Storage Resource Method: Oil & Gas

Volumetric Approach

Estimate produced hydrocarbon and assume it will be displaced by CO_2

STOOIP (STB)

$$G_{CO2} = \boxed{A\, h_n\, \phi_e\, (1-S_w)\, B}\, \rho_{CO2}\, E_{oil/gas}$$

Effective pore Volume (RB)

Initial Hydrocarbon Saturation (fraction)

Reservoir volume factor (STB/RB)

CO_2 density at standard conditions (kg CO_2/MSCF CO_2)

*CO_2-EOR Oil Recovery Factor (bbl/bbl) * CO_2 net utilization (MSCF/STB)*

Parameter	Units*	Description
G_{CO2}	M	Mass estimate of oil and gas reservoir CO_2 storage resource.
A	L^2	Area that defines the oil or gas reservoir that is being assessed for CO_2 storage.
h_n	L	Net oil and gas column height in the reservoir.
ϕ_e	L^3/L^3	Average effective porosity in volume defined by the net thickness.
S_w	L^3/L^3	Average water saturation within the total area (A) and net thickness (h_n).
B	L^3/L^3	Reservoir volume factor; converts standard oil or gas volume to subsurface volume (at reservoir pressure and temperature). B = 1.0 if CO_2 density is evaluated at anticipated reservoir pressure and temperature.
ρ	M/L^3	Density of CO_2 evaluated at pressure and temperature that represents storage conditions in the reservoir averaged over h_n and A.
$E_{oil/gas}$	L^3/L^3	CO_2 storage efficiency factor that reflects a fraction of the total pore volume from which oil and/or gas has been produced and that can be filled by CO_2.

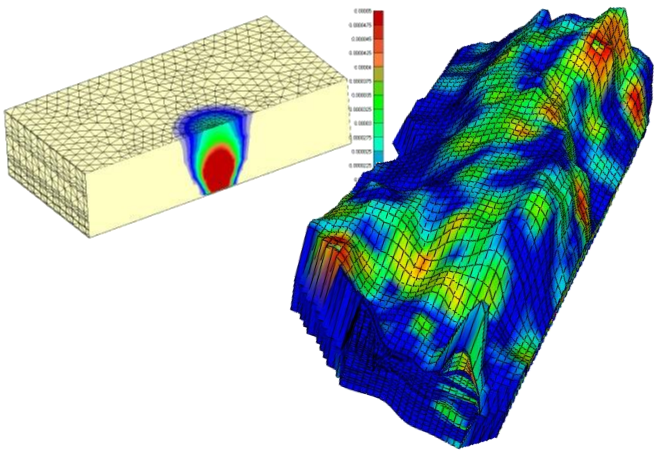
MSCF = thousands of standard cubic feet, where “standard” cubic foot of gas is defined as a cubic foot at a temperature of 21 ºC (70 ºF) and a pressure of 101.35 kilopascals (14.696 psia)

STB is volume of 42 gallons of oil at one atmosphere and a temperature of 60 F (15.556 C)

STOOIP = stock tank original oil in place (in stock tank barrels)

4.2 Applying Reduced Order Models of CO_2 Flooding Scenarios to Characterize Storage Potential

Full-Field Numerical Model

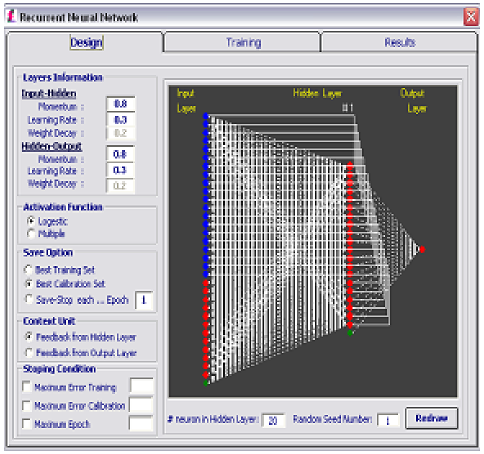


Database of many Simulation Runs

ROM Building

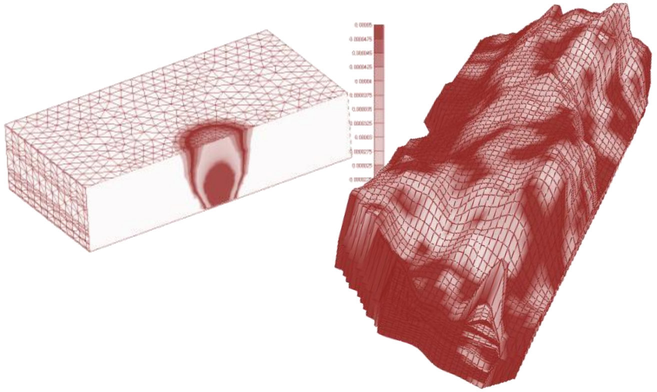
Reduced Order Model

(Response surface/regression approaces, AI techiques)



ROM Validation

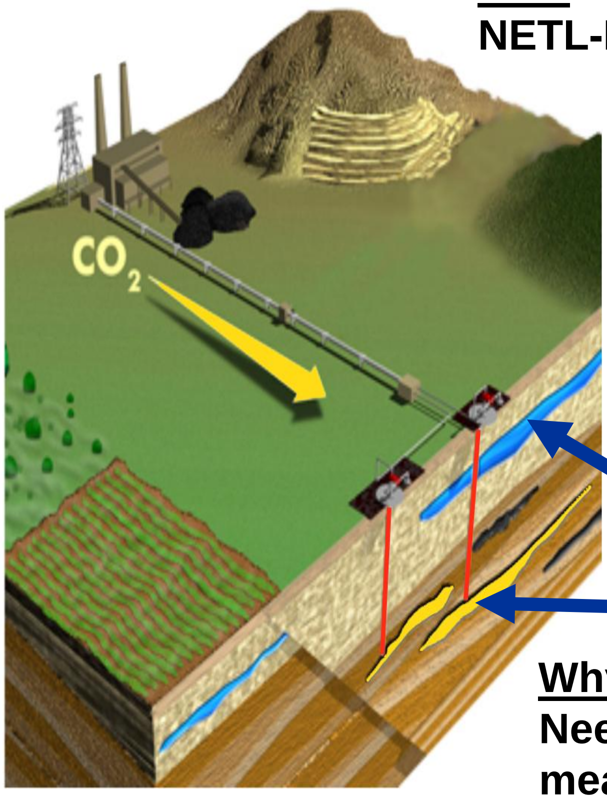
ROM Describes Behavior of Full-Field Model



Exercise ROM to Characterize Storage Efficiency

(with Sensitivity / Uncertainty Analysis)

Task 5.1 Natural geochemical signals
Goals and Objectives



Who

NETL-RUA: NETL, WVU, Pitt, CMU, URS

What

Develop a suite of tracers that can be used for detecting CO_2 or brine leakage from storage formations using naturally occurring isotopes of:

C, Cu, Fe, H, Li, Nd, O, S, Sr, U,

and rare earth elements (REE).

How to account or migration of material
Into shallow aquifers
from target storage strata ?

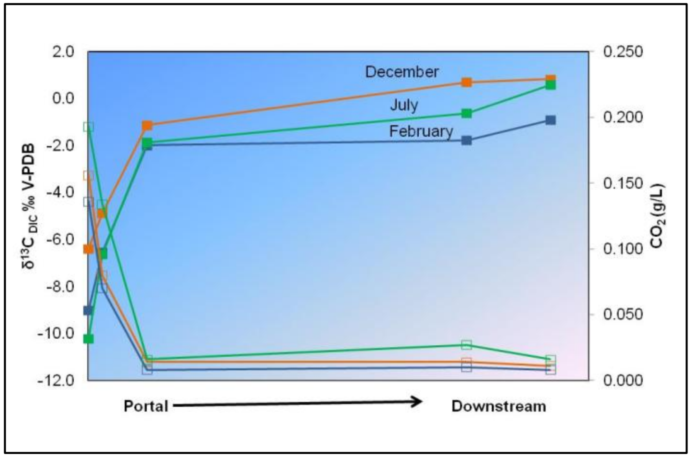
Why

Need to establish CO_2 storage permanence based on measurable parameters as part of an MVA protocol to establish less than 1% CO_2 loss over 100 years.

How

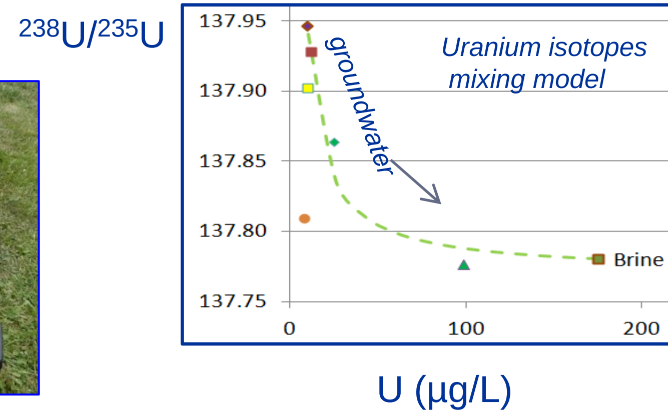
It is anticipated that natural tracers will be used in conjunction with other technologies, including geophysical techniques and transport modeling, as part of an overall MVA protocol to establish less than 1% CO_2 loss over 100 years.

5.1 Progress



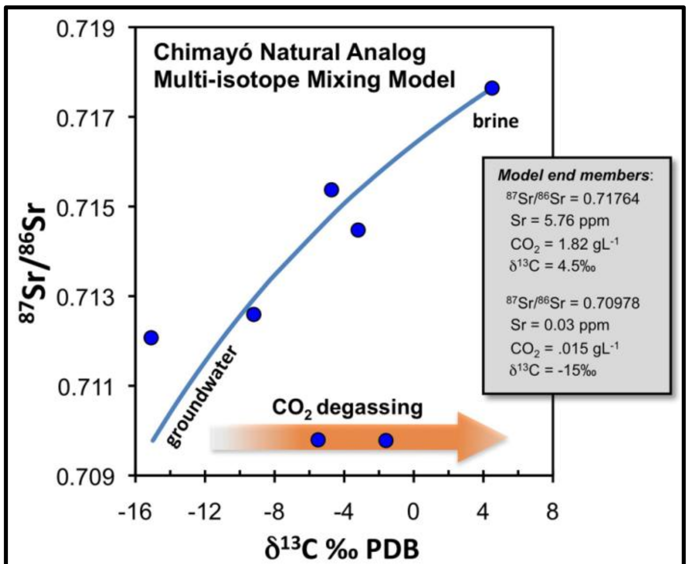
Showed sensitivity of some tracers to physical as well as chemical processes

Field Sampling



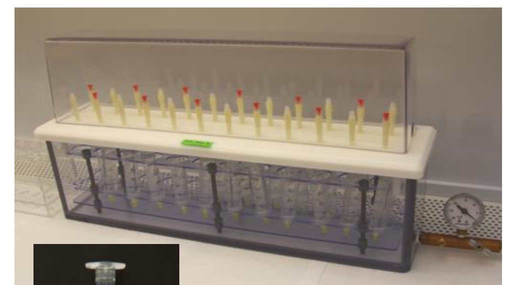
Employed mixing curves and other interpretive techniques to model observed isotopic ratio changes

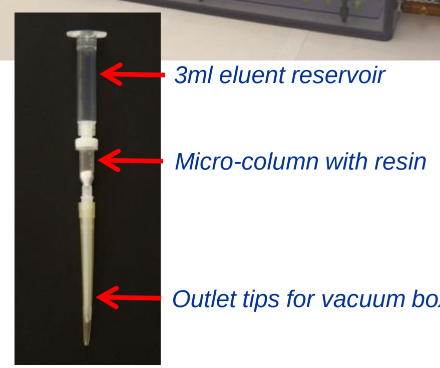
Clean Room Sample Prep



Demonstrated improved interpretation of field data using multiple isotopic ratios

Advanced ICP Instrumental Analysis





Developed methodology for rapid strontium isotope analysis

Task 5.3 - Development of Technology to Monitor CO2 and Pressure Plume – PI- Wells, FAC- Hammack

***Objective:** This task is aimed at using existing geophysical technology to develop a reliable technique to track CO_2 and pressure plumes in the deep subsurface. Models and laboratory experiments are used to enhance interpretation of field data for passive and active seismic monitoring as well as surface deformation measurements.*

***Need:** Monitoring the development of underground CO_2 and pressure plumes is central to modeling the long term and short term fate of CO_2 and evaluating a risk profile that will ensure safe storage.*

Specific Objectives:

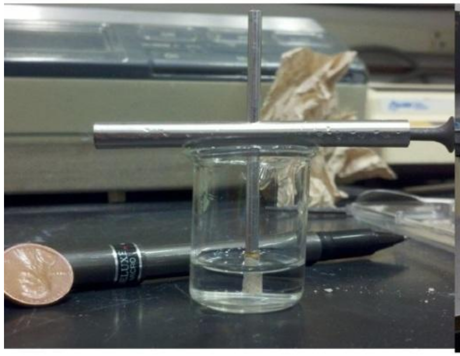
- *Use tomagraphy of microseismic events to evaluate the potential for induced seismicity that could negatively impact structural integrity.*
- *Evaluate the effects of various pore-filling fluids on seismic wave properties by analyzing field cores from various storage sites using NETLs core flow and CT scan laboratories. This includes studying CO_2-rock dissolution to enhance plume detection.*
- *Enhance plume detection by applying 4D and seismic attribute methods to reflection seismic data collected at a field sites and including VSP and well log data.*
- *Evaluate the potential for rock failure during injection by modeling in-situ stress fields. Compare model to surface deformation measurements at test site.*

Task 5.3.2 - Development of Technology to Monitor CO2 and Pressure Plume

CO_2 EXPOSURE

Experiment	Temp (°C)	CO_2 Pressure (psi)	Exposure Time (hours)
2in Core 18%ϕ	50	1950	958.5833333
HP-1 (w/rod)	50	1950	27.05
Hp-3 (w/rod)	50	2000	331.5
HP-2 (w/rod)	50	2000	722.45

CO_2 allowed to dissolve into deionized water with suspended sample in a static reactor vessel. Pore waters are acidified, dissolution occurs. Kinetic factors are H^+ diffusion and reactive surface area.



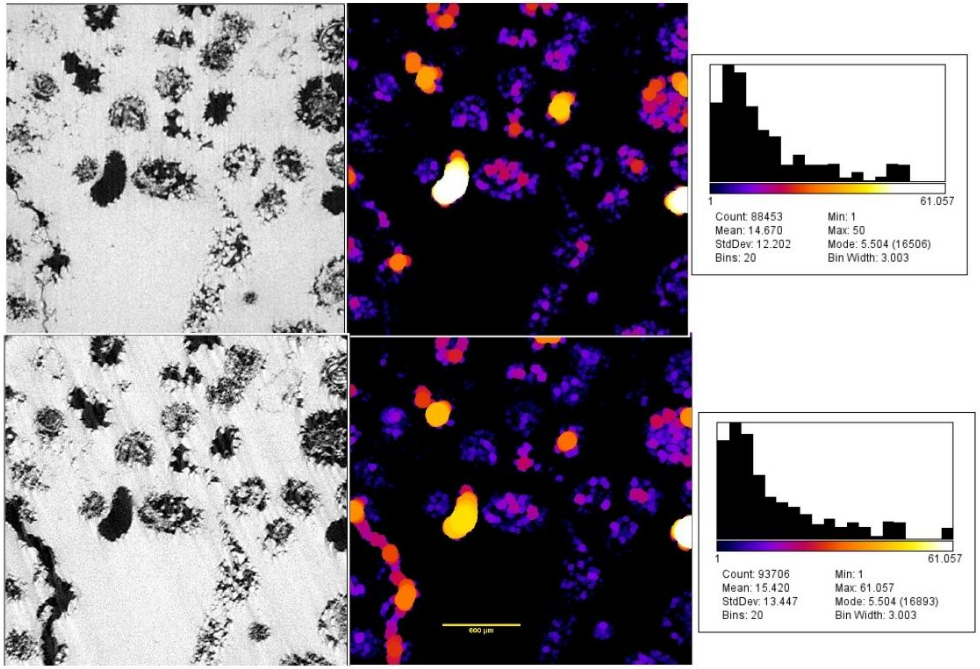


Figure 5. Local thickness calculated on 4X zoom uCT slices before and after CO_2 exposure

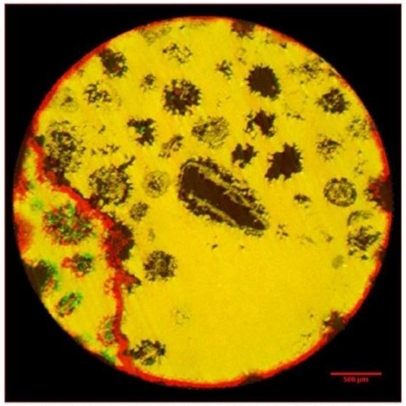
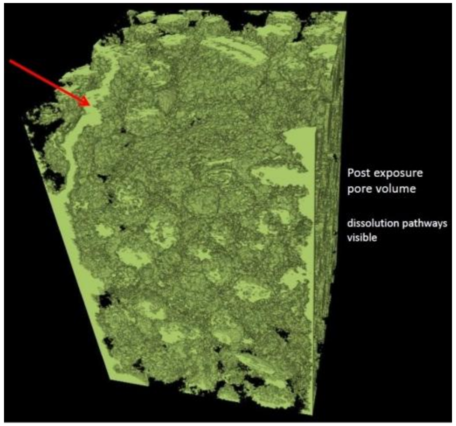
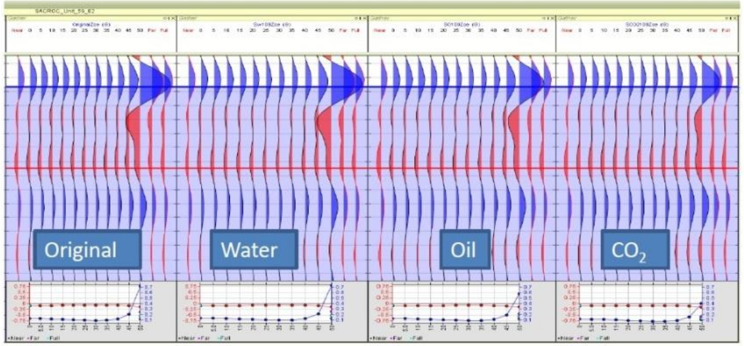


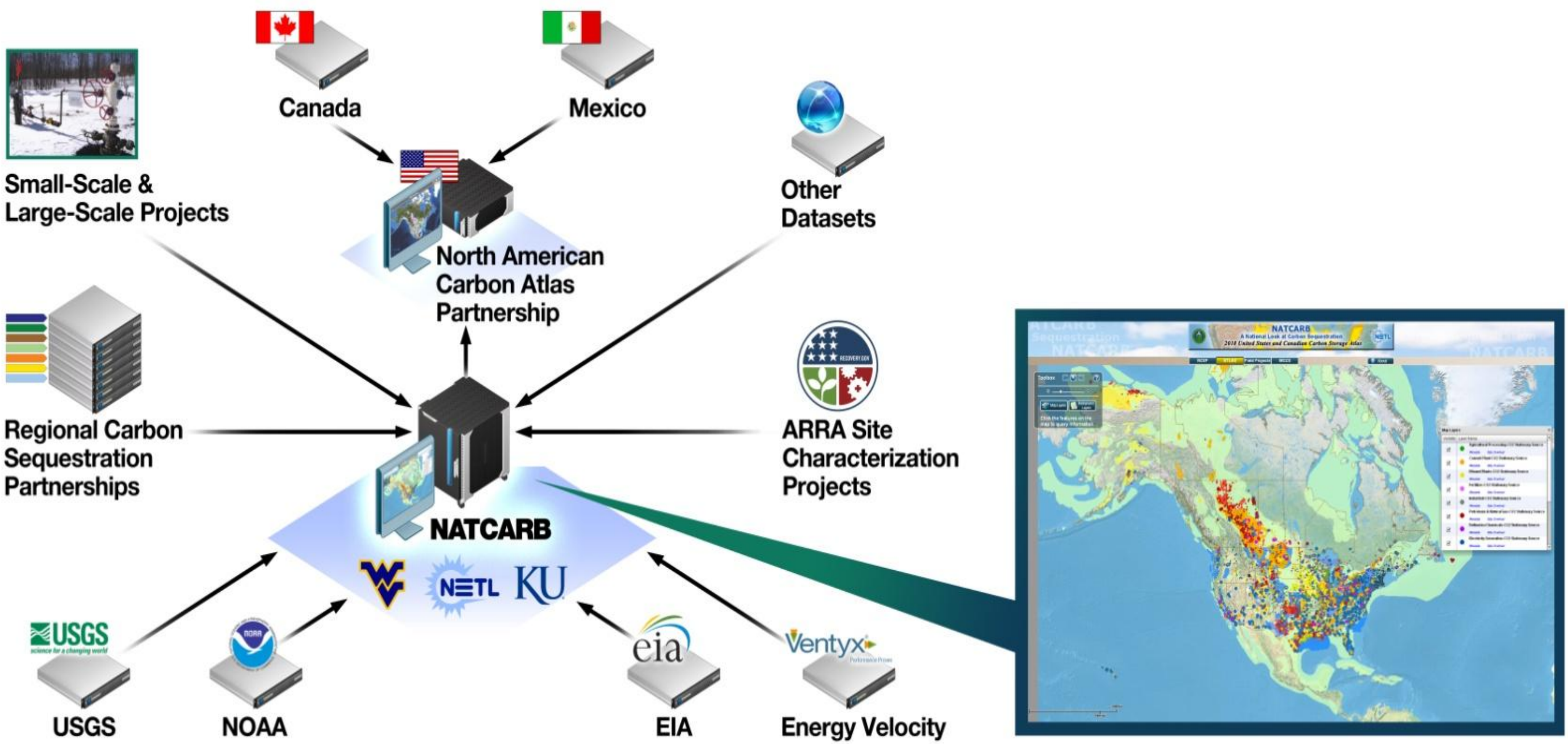
Figure 6. Three-channel, before-after hard-registered volume. Red represents dissolved limestone.





Well logs at two injection sites contain fluid saturation, velocity and density logs.
Synthetic logs are created by simulating different pore filling fluids and calculating the velocity and density response at each point in the reservoir.
Using these well logs, we use the Zoeppritz equations to create synthetic gathers using fluid substitution.

Task 6.1 National Carbon Storage Database and Geographic Information System (NATCARB)



Task 6.1 NATCARB

- **ORD Goals**
  - Improve access and utility of data sets within NATCARB for download and use by scientific researchers.
  - Track web usage more closely on both NETL and WVU servers; produce a combined monthly traffic report.
  - Integrate NATCARB into the EDX for improved searchability options and greater exposure.
- **Atlas 5**
  - Production getting started; expected to take 18 months
  - NATCARB will contribute heavily, as in the past

Energy Data eXchange

Efficient and timely research is driven by:

- Access to existing information
- The ability to quickly share and coordinate data with collaborators
- The ability to disseminate work products as they develop.

- An online platform for rapid and efficient access to priority datasets
- Ability for researchers to share and "publish" online data-driven products, EDXinsights
- A secure environment for multi-organizational research teams to share, build, and collaborate in a common workspace (available spring 2013)
- Online tool to disseminate data, information, and results from DOE's Fossil Energy intramural research portfolios

More information on EDX: http://www.netl.doe.gov/publications/factsheets/rd/R%26D184%20.pdf

Available at: **https://edx.netl.doe.gov**

EDX Version 2, due out March 31st, 2013

- **Group Functionalities:** Ranging from informal collaboration among a subset of colleagues that can be quickly created, to more formal and secure groups that will evaluate and verify the credentials of those requesting to join and participate
- **Data Visualization Tool:** Preview/display files within EDX and assist in determining if the user would like to download those files
- **Collaborative Workspace:** An environment where researchers can quickly and efficiently share data, ideas, and research techniques in a secure and dedicated work space
- **Rapid Response Tool:** Can be utilized in the event of a natural disaster, man-made catastrophe, or any other energy related event where news and data must be quickly coordinated and exchanged
- **Training:** EDX team will be offering in-person training to NETL staff in April. Short video seminars will be available later in the spring to offsite users.

Contacts

- **TC – Brian Strazisar**
- **FAL – George Guthrie**
- **DD's – Karl Schroeder, Jamie Brown, Mary Ann Alvin**
- **TTC's:**

Task #	TTC	Title
2.1	Yee Soong	Impact of Co2-Brine Rock Chemistry on Storage Formations and Seals
2.2	Angela Goodman	Impact of Microbial Processes on Storage Formations and Seals
2.3	Daniel Soeder	Impact of CO2 on Shale Formations as Seals
2.4	Dustin McIntyre	Characterization of Reservoir and Seal Material Performance
2.5	Grant Bromhal	Understanding of Multiphase Flow for Improved Injectivity and Trapping
3.1	Angela Goodman	Improved Mineral Reaction Kinetics
4.1	Daniel Soeder	Methodology for assessment of unconventional systems
4.2	Robert Dilmore	CCUS CO2 Storage Resource Assessment
5.1	Karl Schroeder	Natural Geochemical Signals to Monitor Leakage to Groundwater
5.3	Arthur Wells	Development of Technology to Monitor CO2 and Pressure Plume
6.1	Daniel Soeder	Atlas development and NATCARB
6.2	Kelly Rose	Geodatabase Development - EDX